EVALUATION OF GRANULAR ACTIVATED CARBON FOR THE REMOVAL OF POLYNUCLEAR AROMATIC HYDROCARBONS FROM MUNICIPAL WELL WATER IN ST. LOUIS PARK, MN

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Scope

This report evaluates the use of granular activated carbon for the removal of carcinogenic polynuclear aromatic hydrocarbons (PAH's) and total PAH's from St. Louis Park municipal well water.

Included will be an evaluation of two adsorption system design alternatives and a general estimate of their respective capital and O&M costs.

The municipal well water containing approximately 7000 - 8000 ng/l of total PAH's will be treated at an annual flow rate of 300 million gallons with peak flow conditions to be 1200 gpm. This report evaluates the implications of differing finished water quality levels for PAH's.

The technical information used to prepare this evaluation is a combination of CH2M Hill pilot testing results, field layouts and specifications furnished by ERT, and Calgon's own expertise and data relative to the general performance of activated carbon and adsorption.

Projection of Carbon Performance

Several studies have been conducted relating to the efficacy of granular activated carbon adsorption in producing PAH levels in water below their 10^{-6} Health risk.

Pilot scale column testing by CH2M Hill provides the most useful information. In this study, each of 4 columns in series contained approximately 3 ft. of Filtrasorb 300. The column system was operated at a hydraulic loading rate of 5 gpm/ft^2 with each bed furnishing approximately 4.6 minutes of (empty bed) contact time.

The column test field blank was analyzed to contain from 1.9 to 28.8 ng/l of "other" PAH's composed of napthalene 1-methylnapthalene and 2-methylnapthalene. Similar compounds plus a few other close to their limit of detection were also analyzed in the effluents of each

column totaling 7.9 to 47.1 ng/l through 42 days. Under these conditions there is no evidence of breakthrough of compounds classified as "other" PAH's. Higher concentrations were often noted in later columns in the sequence. Detection of indene and dihydroindene was noted in the blank as well as several effluent samples. While complete breakthrough is not shown by this data, some suggestion of the leading edge of the mass transfer zone is possibly indicated by the increasing trend of dihydroindene in Calgon column #1 effluent on days 30 through 42. This is consistent with CH2M Hill isotherms which show dihydroindene to exhibit among the lowest of adsorption capacities for the compounds detected.

The significance of quinoline in the column effluent samples is unclear. Fluctuation patterns in effluent quinoline concentrations may suggest analytical noise rather than lack of adsorption. The highest level detected was in column #3 effluent on day 2 - lower than the prior 2 columns. If these analyses are correct, however, it would suggest significant nonadsorption of this species.

Total carcinogenic PAH content (excluding quinoline) never exceeded 28 ng/l in influent waters and were never detected to any level in column effluents. Supporting this finding is the isotherm testing which showed total carcinogenic PAH removal at a carbon dosage of 1 mg/l.

The essentially complete removal of all contaminants of interest defines the mass transfer zone under these conditions to be less than 3 feet in length. The Hickok study conducted at 16 gpm/ft^2 and a 5.6 minute contact time defined the mass transfer zone under those conditions to be less than 4 feet in length.

For the purpose of estimated carbon usage, isotherm capacity was used as a basis for judgement. Past field experience has shown this to be a good approximation for dilute, generally homogeneous groundwaters. In a November 18, 1983 report prepared for ERT, we estimated a capacity of 3300 ng/mg from CH2M Hill isotherm data. This was assumed to approximate field loadings. Conservatism was added by

assuming no capacity in a designated mass transfer zone (assumed to be 3 ft.) in column operation. In the assumption that "total" PAH was the controlling parameter the annual carbon utilization rate was estimated to be 13,500 lbs for a flow rate of 300 MGY containing 13000 ng/l of total PAH.

Addressing various water quality levels the following implications are noted for the design described in this report.

(1) Sum of carcinogenic PAH less than 2.8 ng/l and sum of total PAH less than 280 ng/l, where carcinogenic and total PAH are defined in Administrative Order.

If one assumes previously referenced analytical data to be accurate regarding quinoline, attainment of the 2.8 ng/l standard would not be assured by 3, 6, 9 or 12 ft. beds of carbon for any length of time. Even assuming that the pilot test data show no breakthrough of quinoline, some increase in the annual carbon utilization rate may be anticipated. Quinoline, based on its chemical structure, relative polarity, etc. would not be expected to adsorb as well as most PAH's in the water, therefore some degree of breakthrough (from influent levels assumed to be 11-12 ng/l) may be anticipated earlier than the previously anticipated service life. Due to lack of data no quantification can be made to this end.

Other carcinogenic PAH's are not expected to impact on this standard to any extent. CH2M Hill isotherm study has shown complete removal of these species at a projected carbon utilization rate of 2200 lbs/year (based on isotherm results at 1 mg/l carbon dose). This is far below the estimate usage of 13,500 lbs/year.

(2) Conditions sames as (1) except quinoline not considered as a carcinogenic PAH.

As explained previously carcinogenic PAH's other than quinoline are not expected to impact the carbon utilization rate. Removal of total PAH to levels well below 280 ng/l has been demonstrated by a

3 ft. carbon bed through 42 days of operation. A 9 ft. bed operated similarly would obviously achieve the desired level for 126 days at the absolute minimum. Even considering the possibility of early breakthrough of dihydroindene, the maximum carbon utilization rate is not anticipated to be greater than 27,000 lbs/yr. This represents a technical judgment based on general past experience and is thought to be conservative for this application.

(3) Same as (1) except carcinogenic PAH standard to be 28 ng/l.

No impact is anticipated on the estimated usage rate of 13,500 lbs/year. The quinoline concentrations is assumed to be no greater than 12 ng/l and the high adsorptive capacity for carcinogenic PAH's other than quinoline will allow total PAH to be the controlling parameter. Estimated carbon usage would be 13,500 lbs (27,000 lbs anticipated maximum).

(4) Same as (3) except quinoline not considered a carcinogenic PAH

No difference from case (3).

Raising the noncarcinogenic PAH limit would result in a modest decrease in annual carbon usage by allowing a slightly greater amount of carbon to reach full exhaustion in the adsorbers before transfer was required. Even at a treatment goal of 4000 ng/l for these organics, the economy in carbon utilization would only be estimated at 15%. This is based on an assumed 50 percent utilization of the 3-ft. mass transfer zone, as explained in an addendum to a previous report to ERT. Capital savings would not be realized unless a significant portion of the flow were to be by-passed. Treatment goals for carcinogenic PAH's may preclude this option.

Due to the undefined breakthrough characteristics of the various PAH, it would be advisable to conduct pilot scale evaluation to exhaustion with the proposed mini columns prior to or coincidental with the start-up of the full-scale treatment units. Information developed from such a study would refine estimates of capacity and

mass transfer zone in addition to defining breakthrough sequence, more accurately predict transfer intervals and O&M costs, and add insight into the requirements for monitoring frequency. As an alternative similar testing could be conducted by accelerated column testing at Calgon at an estimated cost of $15,000.

Conceptual Design

Two 10 ft. diameter x 14 ft. straight side adsorbers would be operated in parallel. Carbon beds would be approximately 9 ft. deep. Such a system would provide 8.8 minutes of (empty bed) contact time at a peak flow hydraulic loading rate of 7.6 gpm/ft^2. Similar adsorption systems have operated for potable use of contaminated groundwater at many locations throughout the United States, although not with PAH as the controlling contaminants. The adsorbers would be located after sand filtration. With the documented problems involving silt and iron precipitation, it is advisable to remove these constitutents by a unit operation prior to adsorption. This will prevent possible channelization of flow in the adsorbers or dead plugging leading to premature breakthrough.

The adsorption effluent must be chlorinated for potable use. The sand filter effluent is expected to contain some residual chlorine from the prechlorination step. However, activated carbon effectively removes free chlorine from the treated water. This means that some extra chlorine will be required in the postchlorination step.

No transfer tank is incorporated into the conceptual design. At the projected carbon usage rates and infrequent transfers, extra freight charges in terms of an empty trucks would be considerably lower than costs associated with additional capital equipment.

The adsorbers would be located inside a building to be constructed. This approach has been found to be more effective in terms of efficient system operation in northern climates in addition to providing a superior work environment for site operators.

The projected pressure drop at 1200 gpm with Filtrasorb 300 in this system with 6 inch underdrains would be 10 psi or less assuming efficient operation of the sand filters upstream.

In this system of parallel operation the activated carbon will not be fully exhausted at the time of transfer. It has been estimated that 67% of the carbon's ultimate capacity for PAH adsorption will be utilized. This is based on a 3-ft. mass transfer zone assumed to yield no effective adsorption capacity. At the projected carbon usage rates, the O&M savings resulting from full carbon utilization would not justify the costs associated with the additional capital equipment required for series operation.

A backwash tank, pump, and controller is included in the conceptual design. This provides the required supply of treated water needed for backwashing.

Additional adsorber(s) can be easily added to the design if decreased carbon use or an additional safety factor is desired. A transfer tank can also be incorporated if the carbon usage is significantly higher than the estimate.

The above represents a system pre-engineered by Calgon for modular implementation and ease of transport to applications of this size. The vessels are available from stock and have performed successfully in potable water treatment applications with this flow requirements.

System Cost Estimates (July 1984)

Capital Item	Est. Cost
2 Backwash Adsorption Columns (incl. 6" underdrains, food grade lining and face piping)	$135,000
Building Expansion*	$20,000
Column & Building Foundation	$12,000
Backwash Tank, Pump and Controls	$15,000

Capital Item	Est. Cost
Connecting Piping and Instrumentation (parallel operation)	$28,000
Field Assembly (incl. freight, permits, testing, crane, site prep, etc.)	$102,000
Initial Carbon Fill 40,000 lbs F-300 (incl. freight)	$40,000
Cast Iron Pipe Retrofit	$36,000
Pilot Columns	$8,000
SUB TOTAL	$396,000
Contingency 15%	$59,000
SUB TOTAL	$455,000
Engineering, Legal, Administration	$46,000
TOTAL ESTIMATE COST	$501,000

O&M Item	Est. Cost
Granular Activated Carbon Replacement (13,500 lbs/year)	$13,500**
Maintenance	$4,000
Labor	$7,000
Utilities (excludes well operation)	$4,000**
Additional chlorine required (for carbon effluent)	$600**
ESTIMATED TOTAL ANNUAL O&M	$29,100***

*Stock prefabricated sheet metal. No brickwork included.
**Costs vary proportionally to flow, others relatively constant.
***Exclude monitoring costs.

Alternative System

The following refers to an adsorption system similar to that refered to in the Administrative Order, which is based on a conceptual design by CH2M Hill.

This system would be composed of three 16 ft. diameter x 5 ft. straight side adsorbers, to be operated in series made with one adsorber in stand-by. At standard Filtrasorb 300 density bed height would be about 3.5 ft. per vessel. Piping would be such to allow various combinations of series/parallel operation. The hydraulic loading rate under peak flow would be 6.0 gpm/ft^2. The system would provide 8.8 minutes of (empty bed) contact time if two vessels were in operation under peak flow. CH2M Hill's design included a 6700-gallon transfer tank, but this has been excluded to a allow for consistent cost comparisons for the same reasons described earlier.

To appraise on an equivalency basis, it was assumed this system was to be operated downstream of the sand filters, contained within a building and require some additional postchlorination. Separate backwashing capability was also assumed for this system.

In relation to the previously described adsorption system this design allows for complete carbon exhaustion under normal circumstances, based on staged series operation of the three columns. This results in a decrease of annual carbon usage and a savings of annual cost for this of $4500 assuming estimated carbon usage rates are accurate.

The amount and design of capital equipment allows for some flexibility in operation. Series operation with a stand-by offers an additional safety factor against a non-anticipated breakthrough. Whether this is a significant factor or not is debatable in the absence of pilot column testing to exhaustion.

With shorter bed depths, lead column breakthrough would be noted earlier, however, frequent analysis would not be required until breakthrough developed in the second bed in series. Based on pilot testing, the mass transfer zone under these conditions has been found to be less than the depth of carbon in one vessel. This would theoretically allow lead column breakthrough to progress to 100% before any breakthrough in the second column in sequence is noted.

With the lower hydraulic loading rate and shorter bed depth a slight improvement in pressure drop could be anticipated in this sytem over that previously described, however, the additional piping and underdrains would negate much of this advantage, leaving both systems almost equivalent in this regard.

Due to the larger diameter of adsorption vessels in this system, additional backwashing capacity is required for this system. This increased capacity is reflected in the capital cost for the backwash equipment.

In regard to attainment of the water quality goals, this system would compare nearly equivalently to the previous design. Attainment of the 2.8 ng/l goal for carcinogenic PAH including quinoline could not be assured at any time if analytical testing is accurate. If analytical findings amount to standard data scatter regarding quinoline, the impact on service life cannot be accurately predicted. The question of timing for 25% quinoline breakthrough vs 3% breakthrough for total PAH cannot be answered from the supplied or existing data. Based on general chemistry of quinoline, impact on service life for 2.8 ng/l treatment goal is a possibility.

Carcinogenic PAH's other than quinoline are expected to show no impact on service life at either the 2.8 or 28 ng/l goal based on isotherm results. Quinoline is not expected to impact service time at the 28 ng/l goal due to its anticipated low concentration in the feed. The total PAH treatment goal of 280 ng/l is expected to be achieved at an annual carbon usage of 9000 lbs of carbon, assuming that staged series operation allows the carbon in the lead absorber to

achieve isotherm level capacity. Even in the case of an unexpected early bleed through of compounds such as dihydroindene, the annual exhaustion rate would not be expected to change more than by a factor of two.

In assuming total exhaustion of carbon in the lead bed before any breakthrough is detected in the finished water, there would be no advantage in capital and O&M savings by raising the noncarcinogenic PAH level by any degree.

System Cost Estimates (July 1984)

Capital Item	Est. Cost
3 - 16ft. diameter x 5' straight side adsorbers x 5/8" wall thickness (incl. food grade lining, 6" underdrain, face piping	$228,000
Foundations	$40,000
Building Expansion* (for 4 vessels)	$110,000
Backwash Tank, Pump & Controls	$28,000
Connection Piping and Instrumentation(series/parallel operation)	$103,000
Field Assembly (inlet freight, permits, testing, crane, site prep etc.)	$158,000
Cast Iron Pipe Retrofit	$36,000
Initial Fill 60,000 lbs F-300 (incl. freight)	$60,000
Pilot columns	$8,000
SUB TOTAL	$771,000
Contingency 15%	$106,000
SUB TOTAL	$877,000
Engineering, Legal, Administration	88,000
TOTAL ESTIMATED COST	$965,000

*Reconsideration may be given to locating this system outside and adding heat tracing and insulation. Cost based on stock prefabricated sheet metal building.

O&M Item	Est. Cost
Activated Carbon Replacement (9000 lbs/year)	$9,000*
Maintenance	$6,000
Labor	$10,000
Utilities (excludes well operation)	$4,000*
Additional Chlorine Requirement	$600*
ESTIMATED TOTAL ANNUAL O&M	$29,600**

*Costs vary proportionally to flow, others are relatively constant.
**Excluding monitoring costs.